Food for thought:
crop responses to climate change

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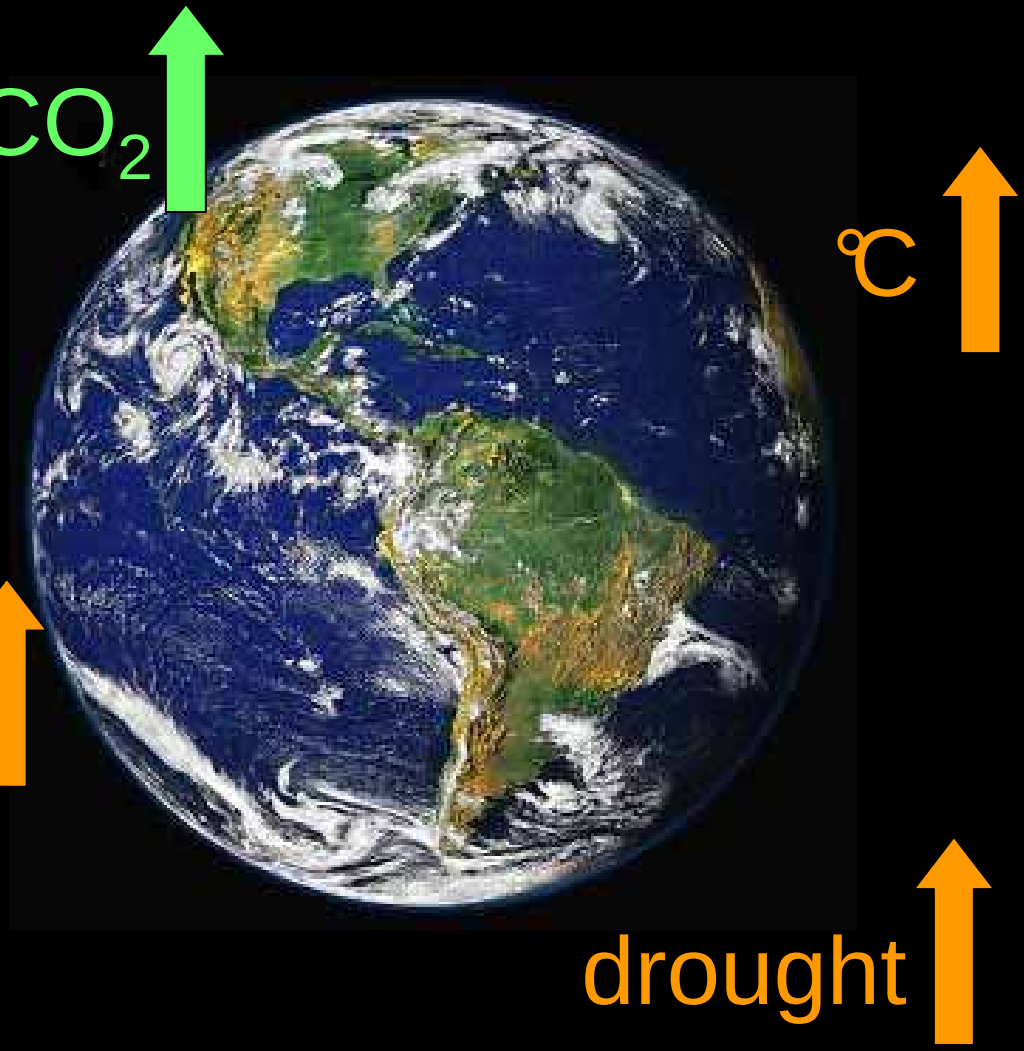
University of Illinois


1) How will rising CO_2 contribute to climate change impacts on crop production in the 21st century?
2) How can we improve the situation?

Climate change is multifaceted



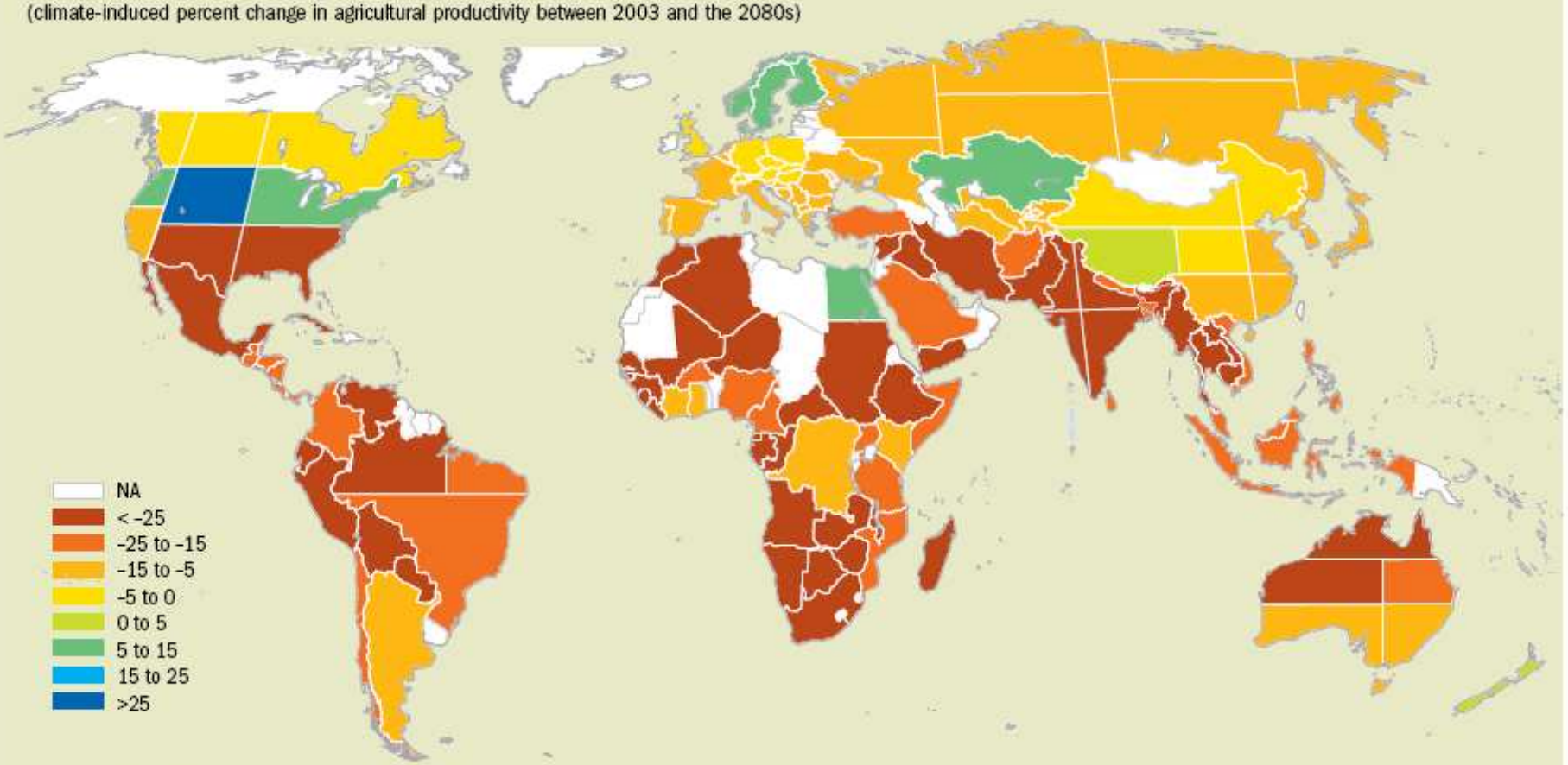
% change in crop yields in 2080 considering altered temperature, rainfall and socio-economics but NO carbon dioxide fertilization of plant growth

Map 1

Without carbon fertilization

If there are no beneficial effects from increased carbon dioxide, agricultural output declines almost everywhere and catastrophically closer to the equator.

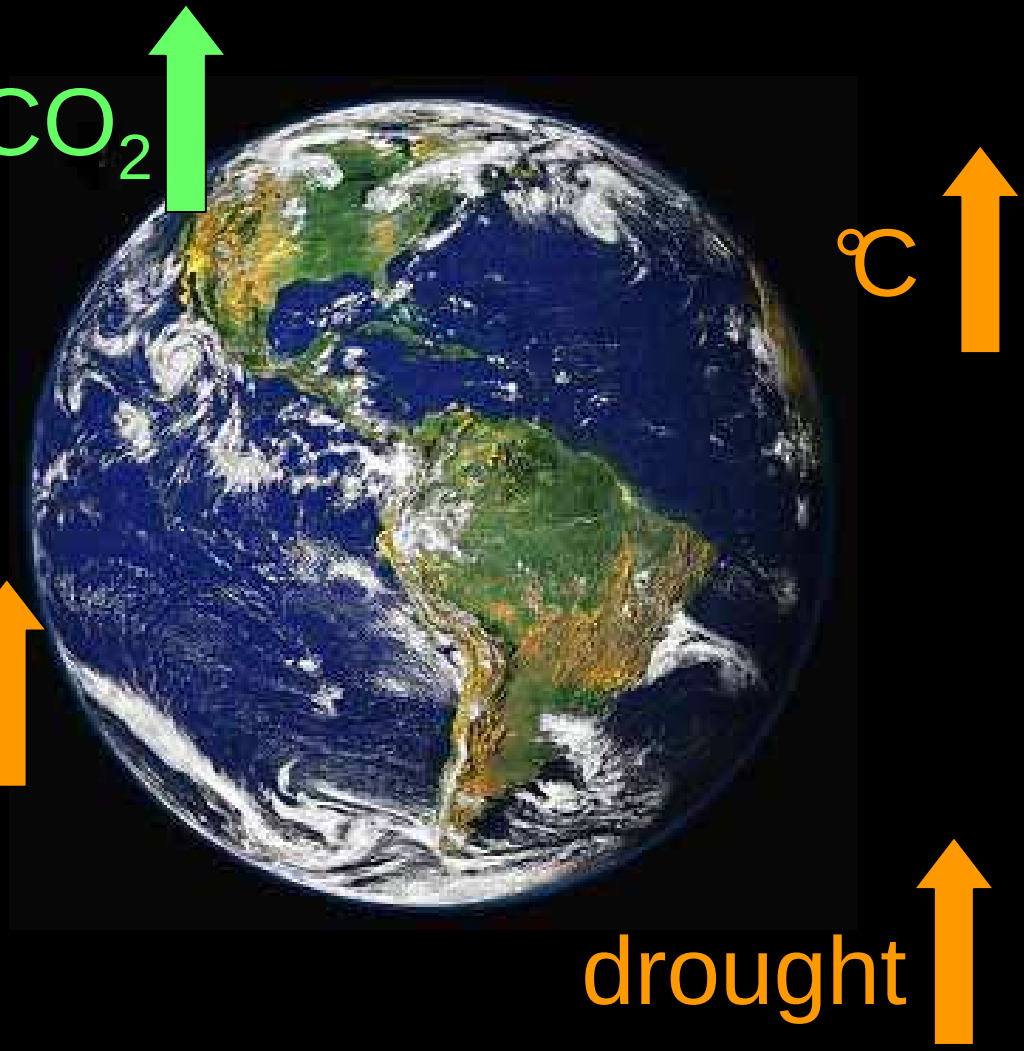
(climate-induced percent change in agricultural productivity between 2003 and the 2080s)



Source: Cline (2007).

Note: NA refers to "not applicable" for Alaska and northern Canada, and to "not available" elsewhere.

Climate change is multifaceted



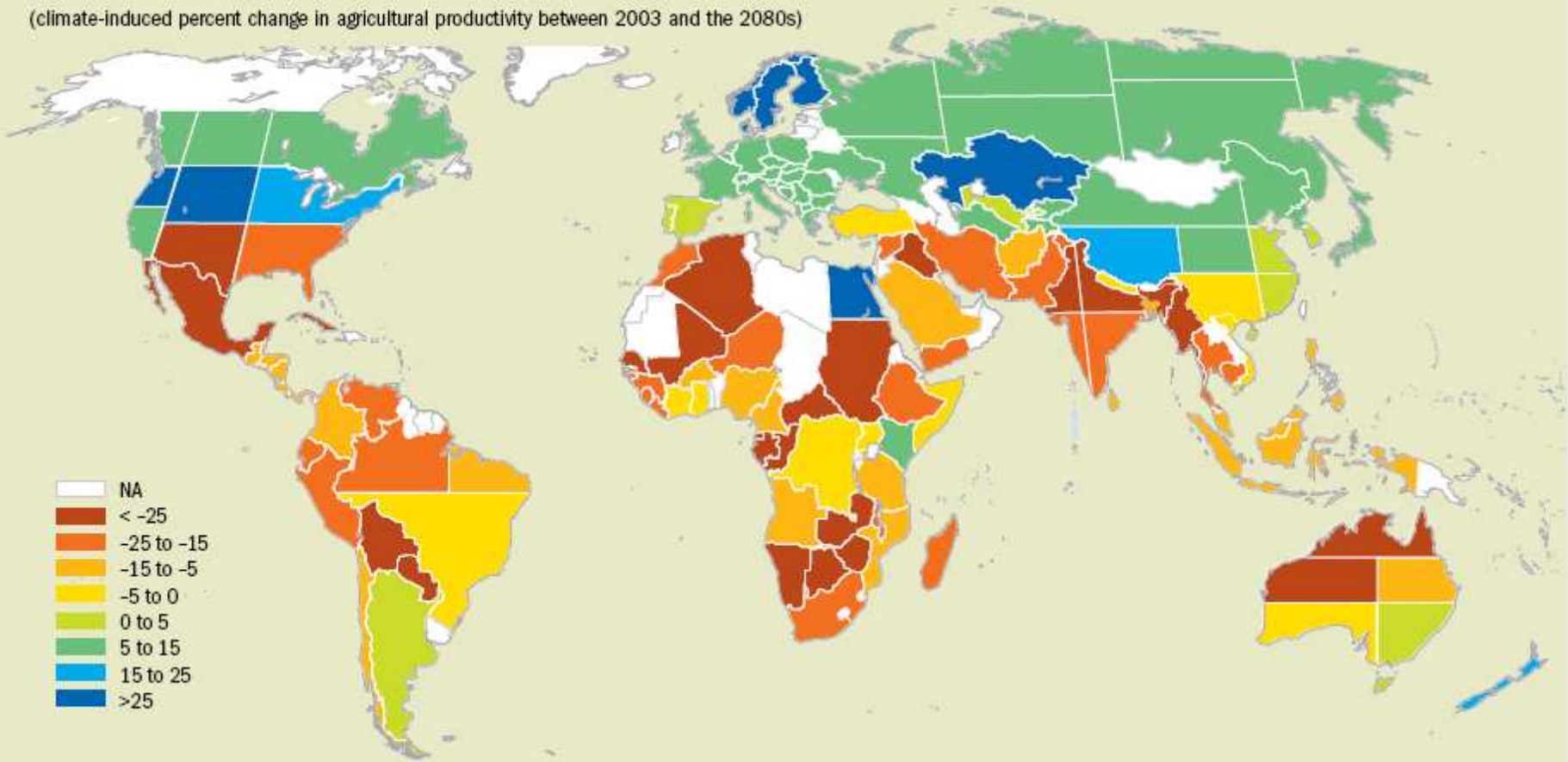
% change in crop yields in 2080 considering altered temperature, rainfall and socio-economics PLUS carbon dioxide fertilization of plant growth

Map 2

With carbon fertilization

If some crops benefit from increased carbon dioxide, the global impact is less dire and those areas farther from the equator may see some increases in agricultural productivity.

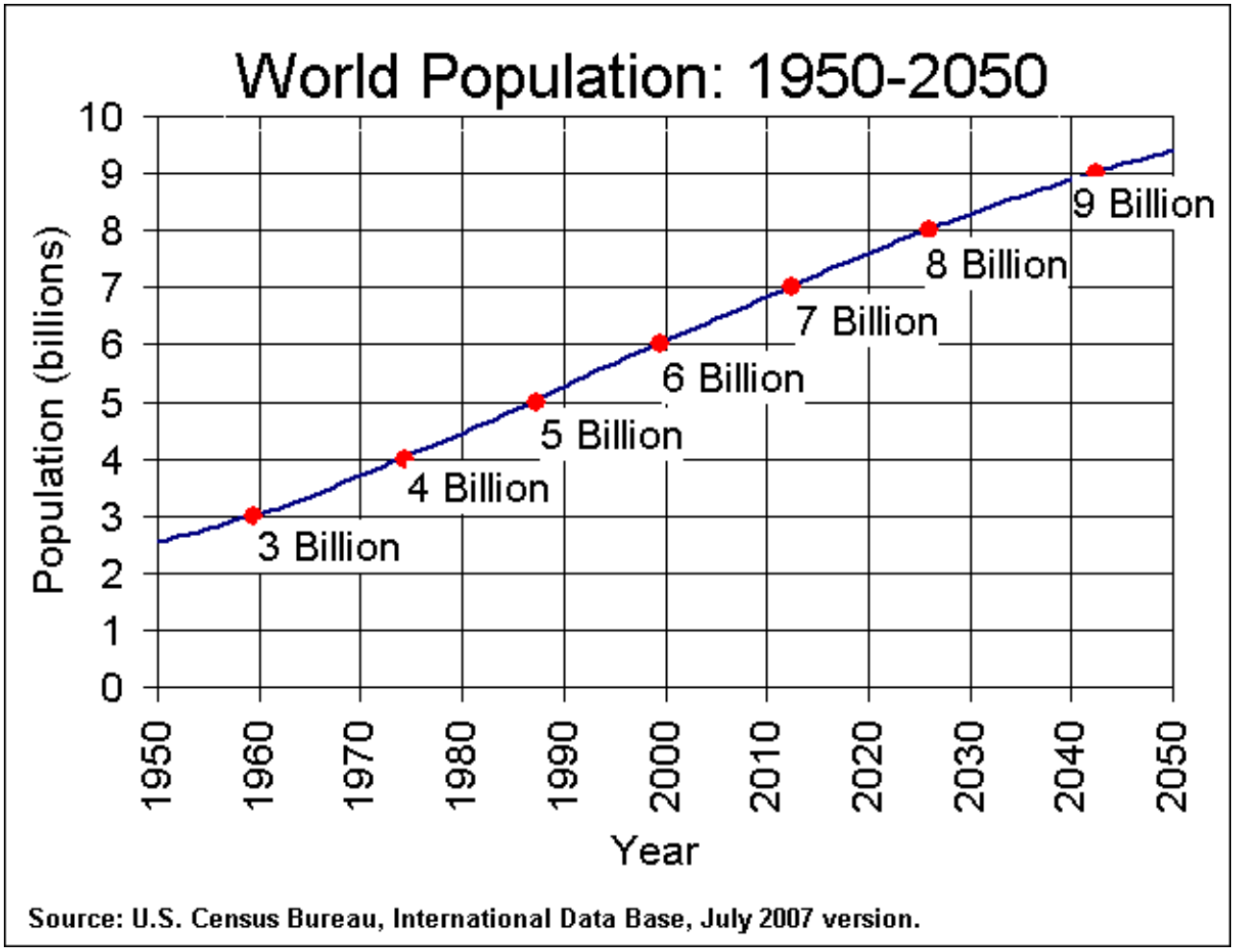
(climate-induced percent change in agricultural productivity between 2003 and the 2080s)



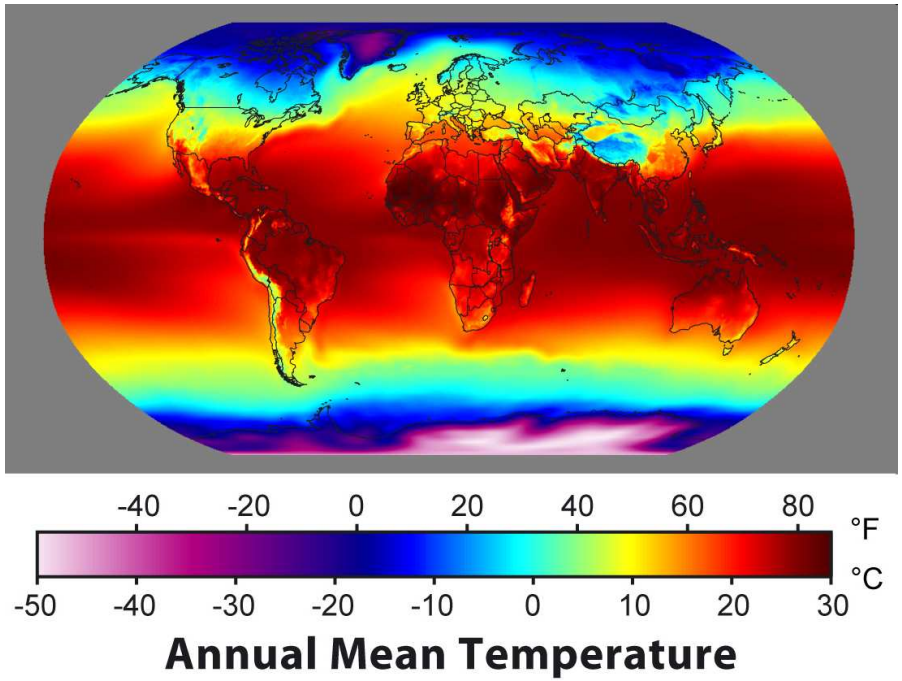
Source: Cline (2007).

Note: NA refers to "not applicable" for Alaska and northern Canada, and to "not available" elsewhere.

And…

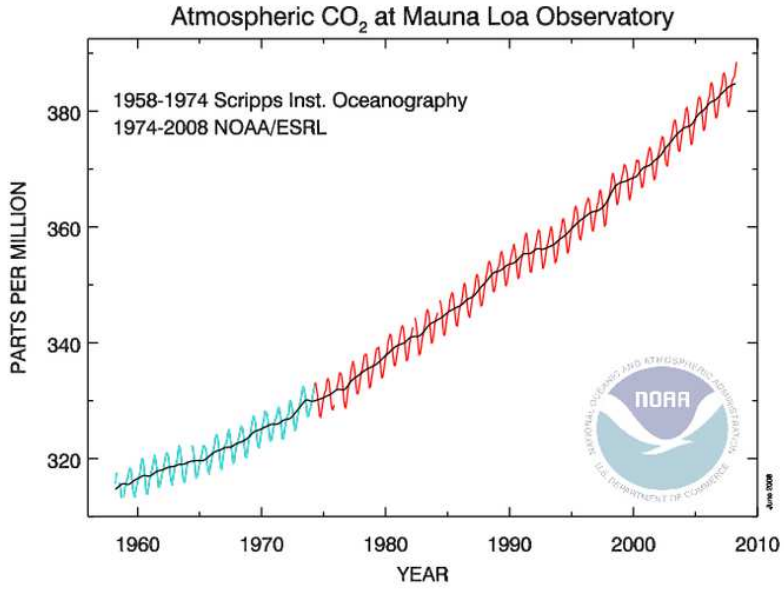


So our ability to feed everyone will be challenged like never before.



The impacts of CO_2 on crops have only been fully appreciated in the last 30 years.

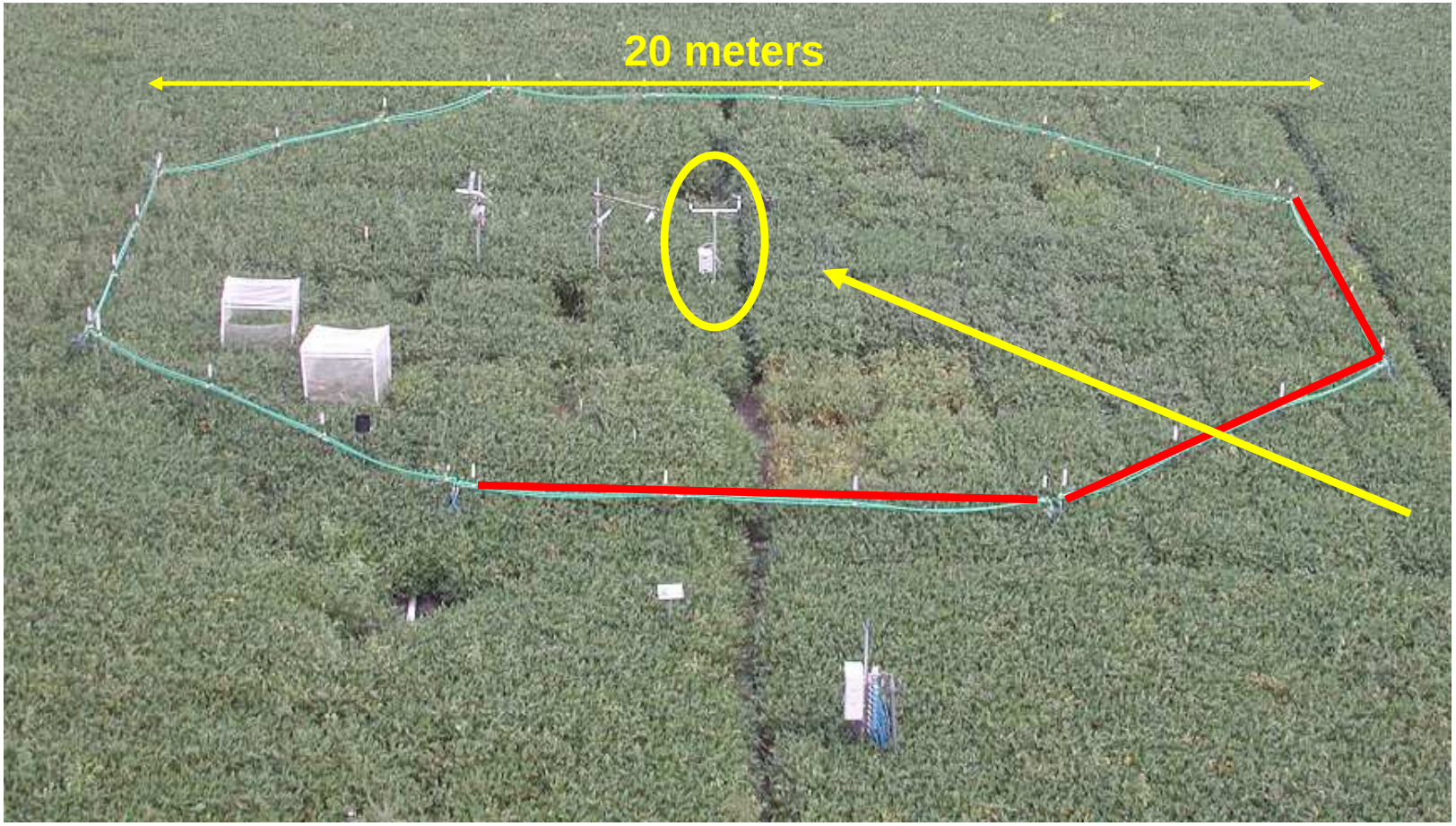
Also…

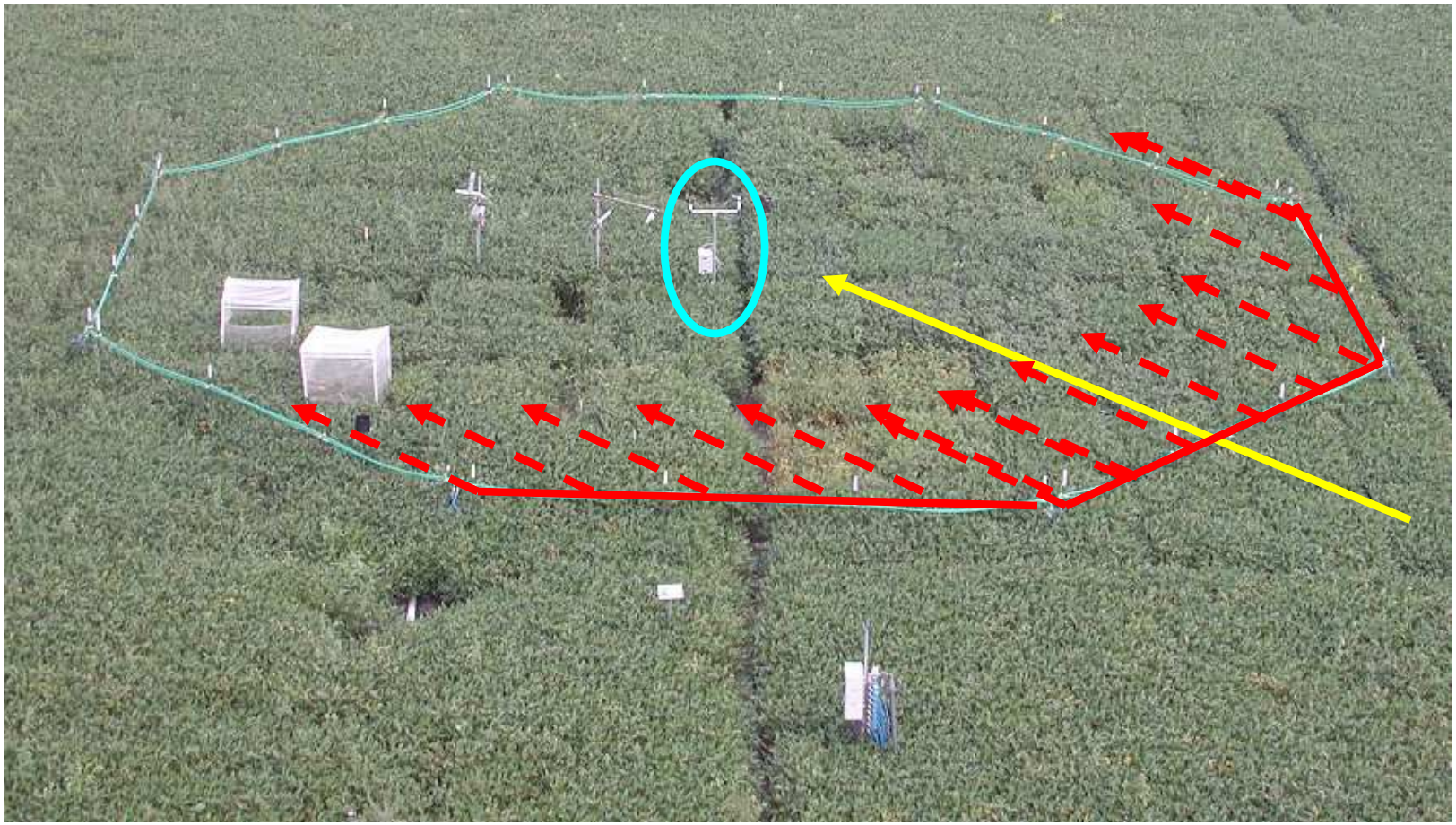


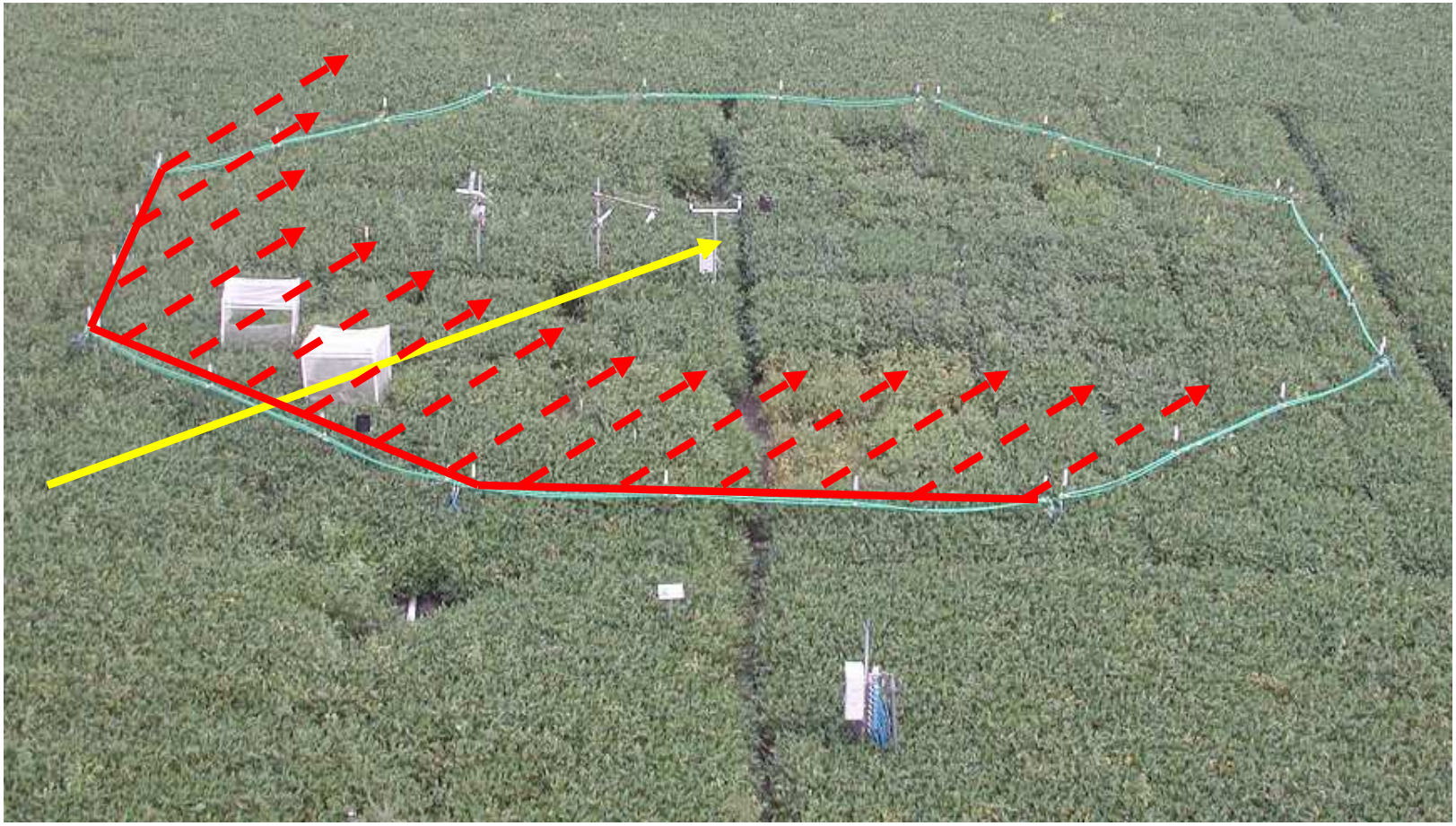
Unlike temperature and precipitation, there are not consistent spatial and temporal patterns of CO_2 that can be studied and used to develop improved crops.

Soybean Free Air gas Concentration Enrichment Facility (SoyFACE)

www.soyface.illinois.edu

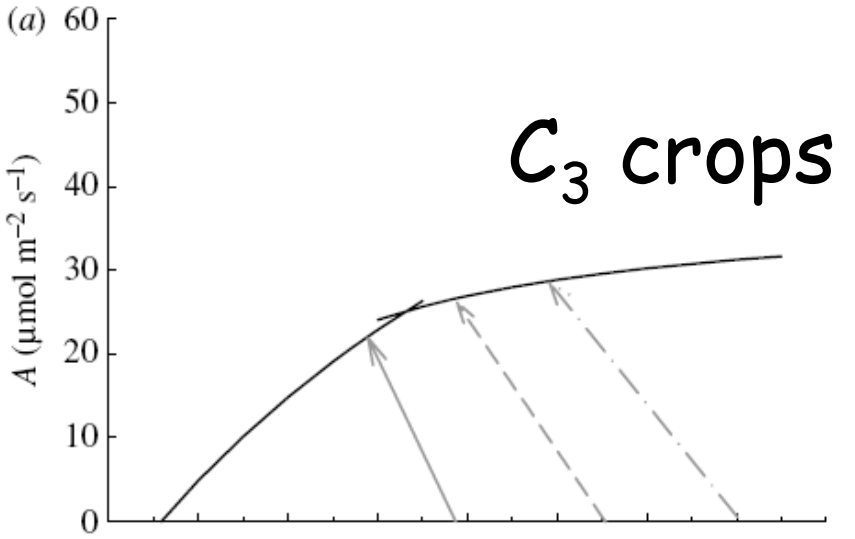

20 meters



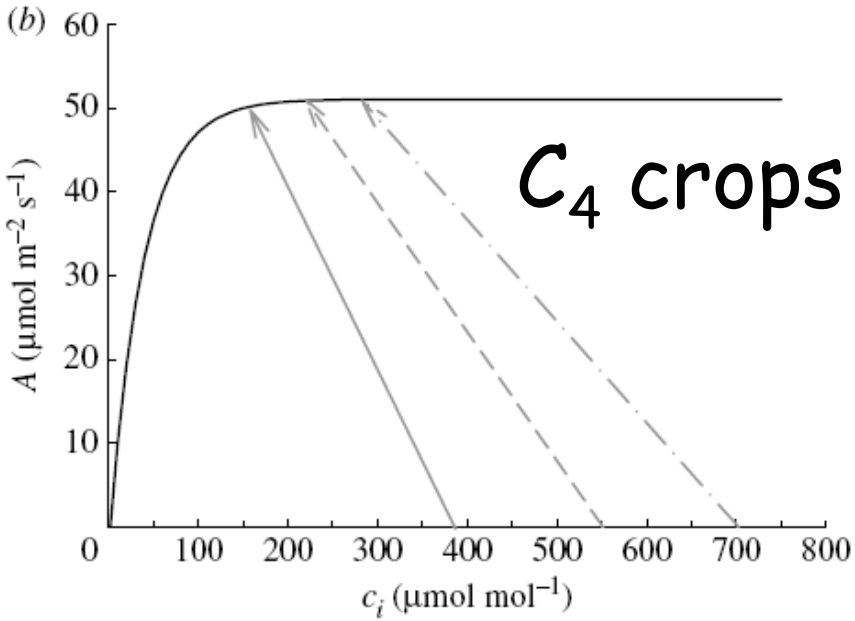


We use this facility to understand how plants respond to elevated CO_2. This is the first step in crop improvement.

Photosynthetic responses to rising CO_2



C_3 crops



C_4 crops

Soybean

Wheat

20 % gain in 2050

Maize

No gain

Photosynthesis

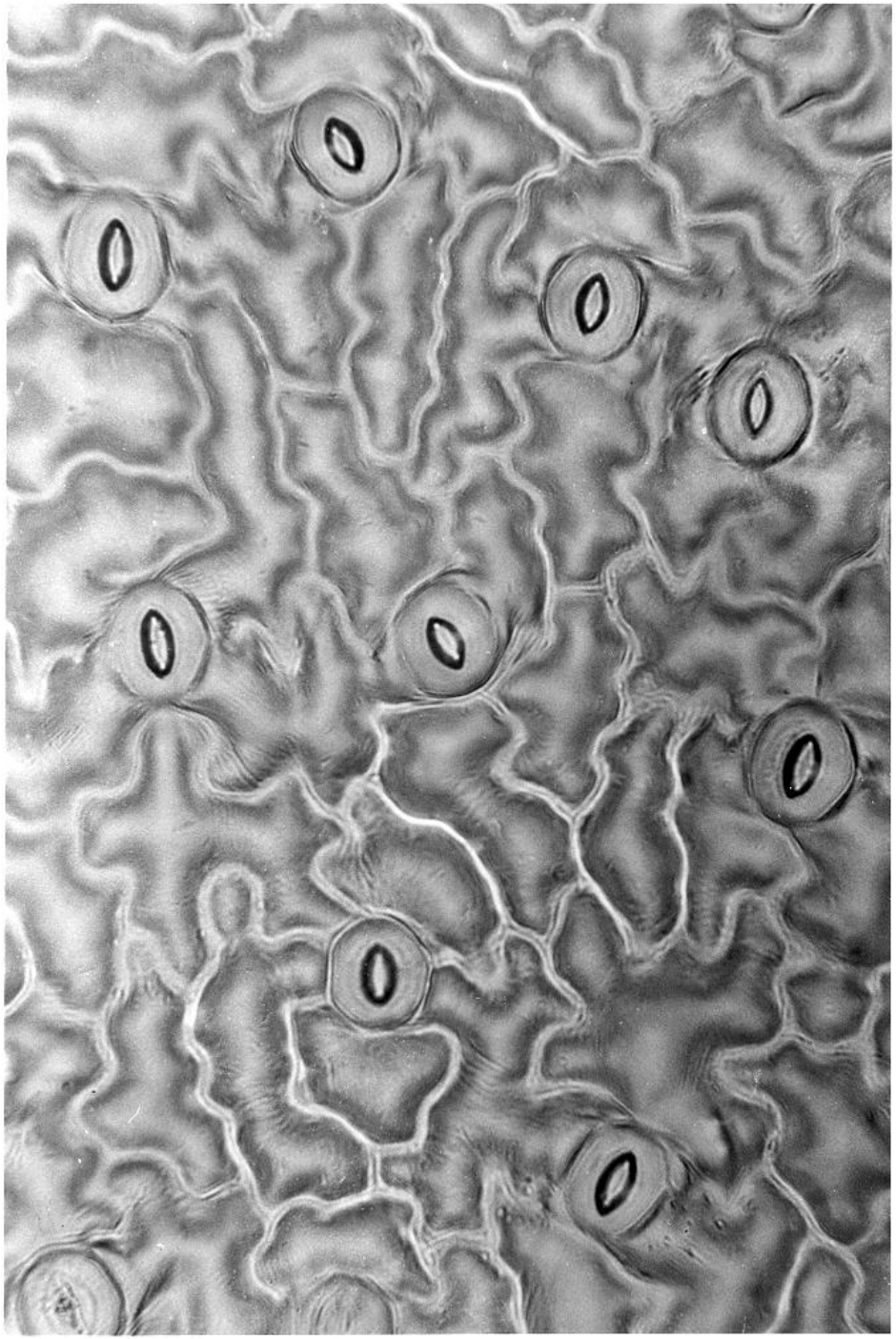
$H_2O + CO_2 \longrightarrow$ sugars

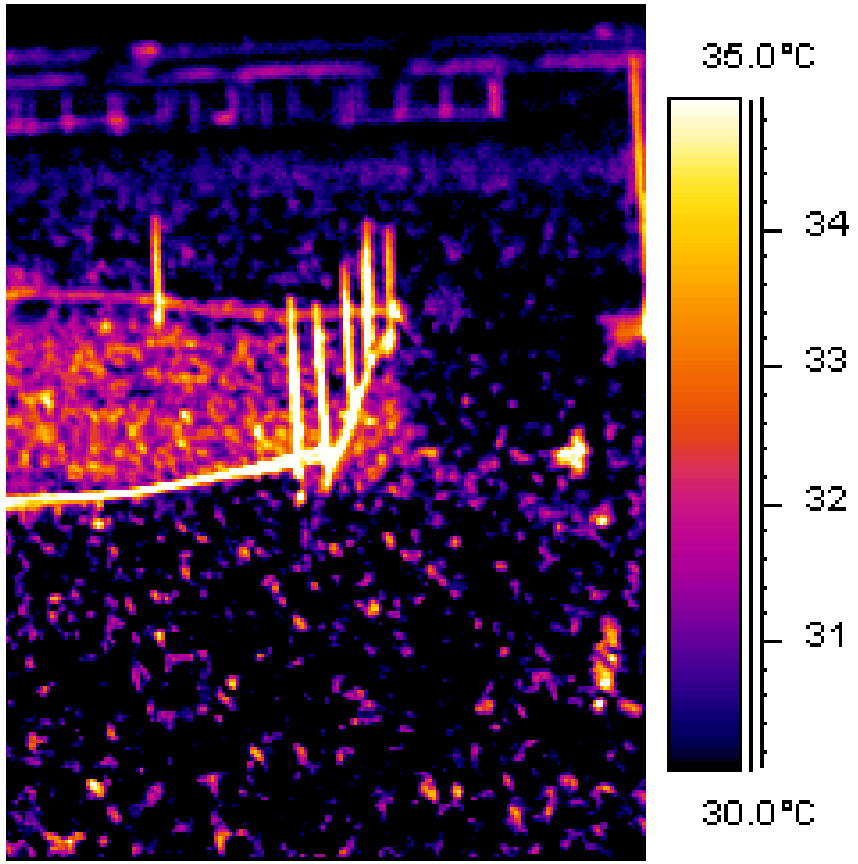
↓

growth

↓

yield




35.0°C
34
33
32
31
30.0°C

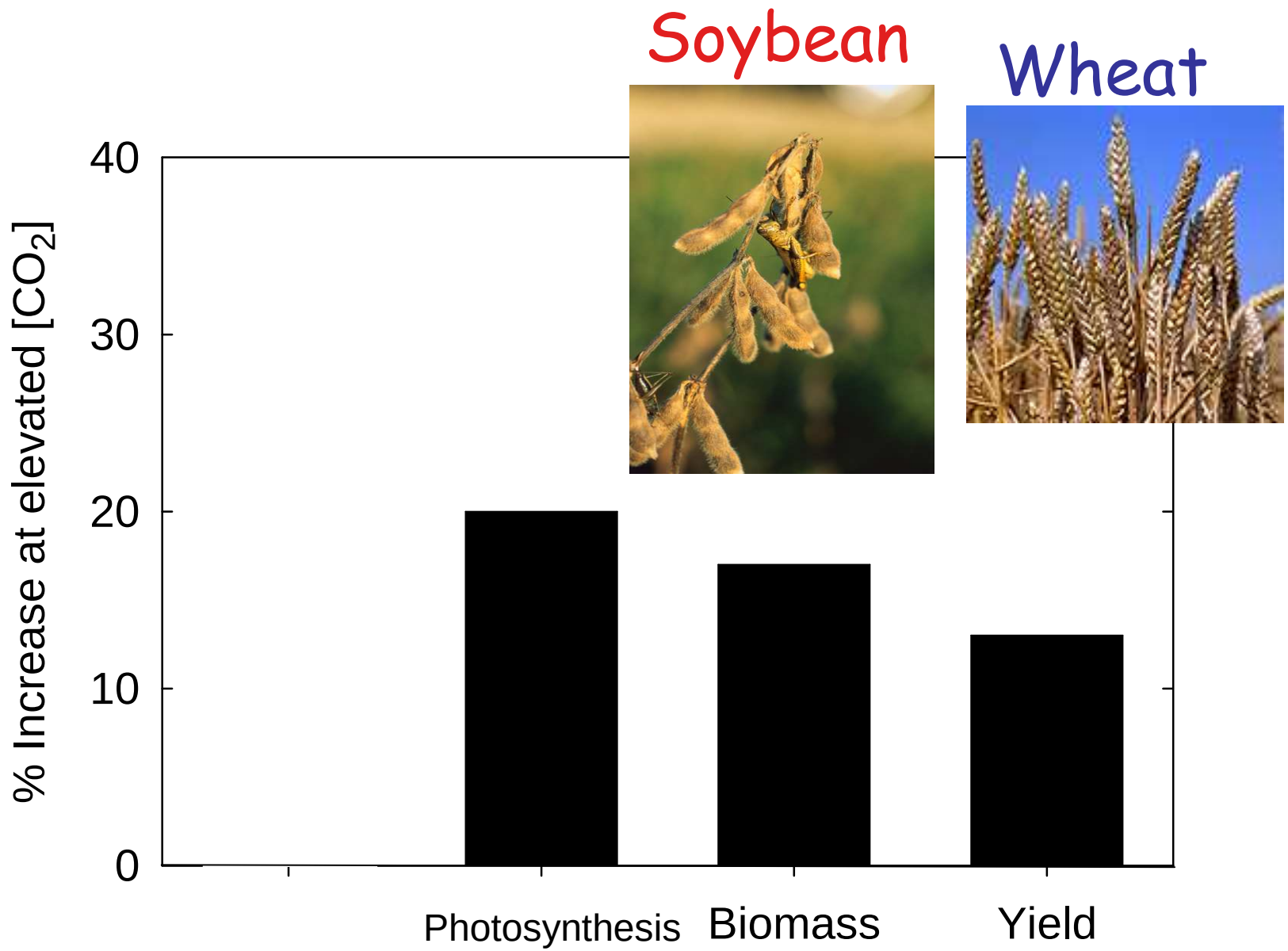
Benefits to C_3 and C_4 crops

Today's [CO_2]

Leaf curling

2050's [CO_2]

No leaf curling

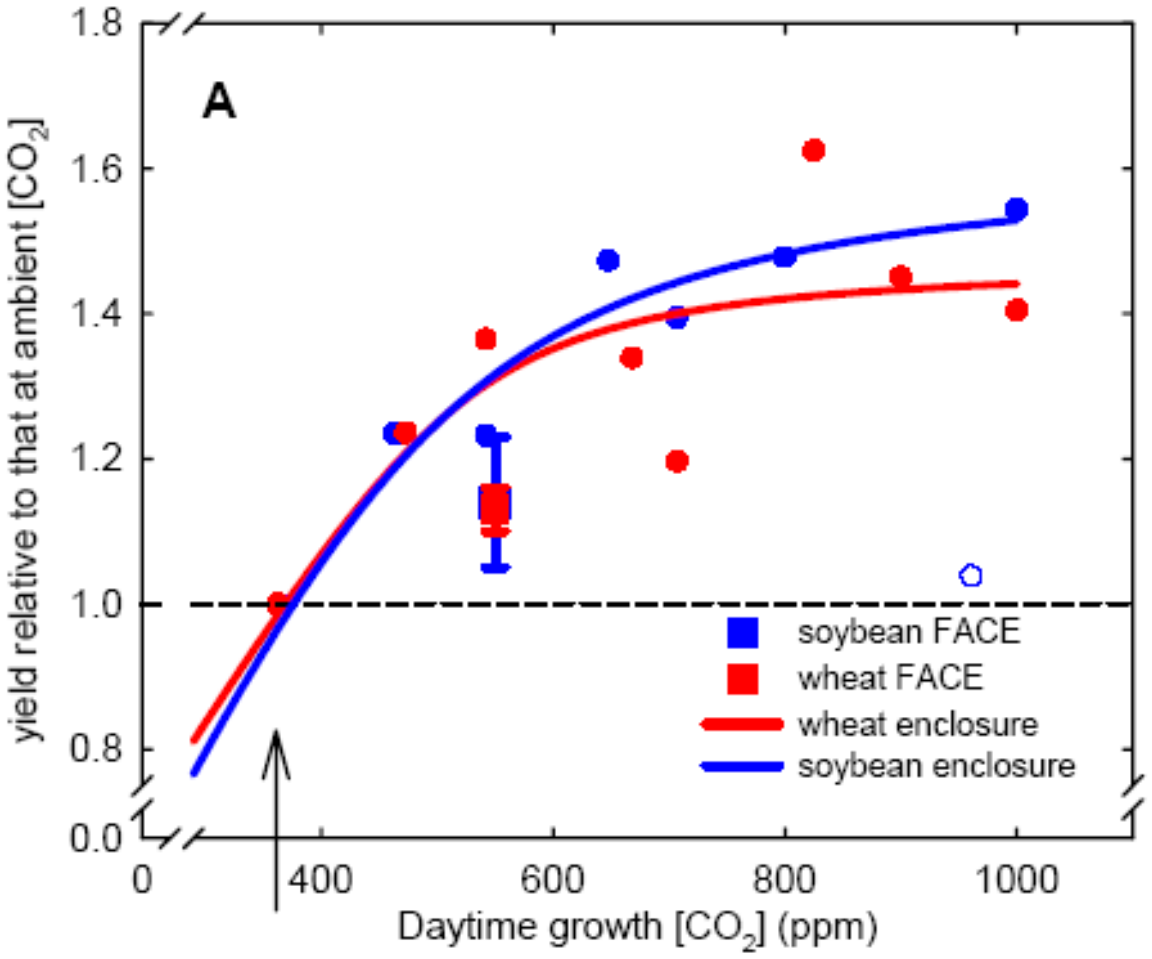

Soybean
Wheat
% Increase at elevated [CO2]
40
30
20
10
0
Photosynthesis
Biomass
Yield

Soybean

Wheat

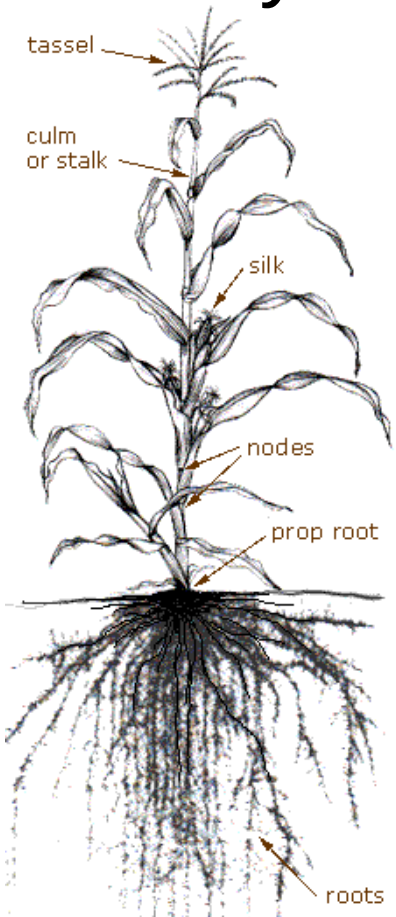
Food for Thought: Lower-Than-Expected Crop Yield Stimulation with Rising CO_2 Concentrations

Stephen P. Long,[1,2,3]* Elizabeth A. Ainsworth,[4,1,3] Andrew D. B. Leakey,[3,1] Josef Nösberger,[5] Donald R. Ort[4,1,2,3]



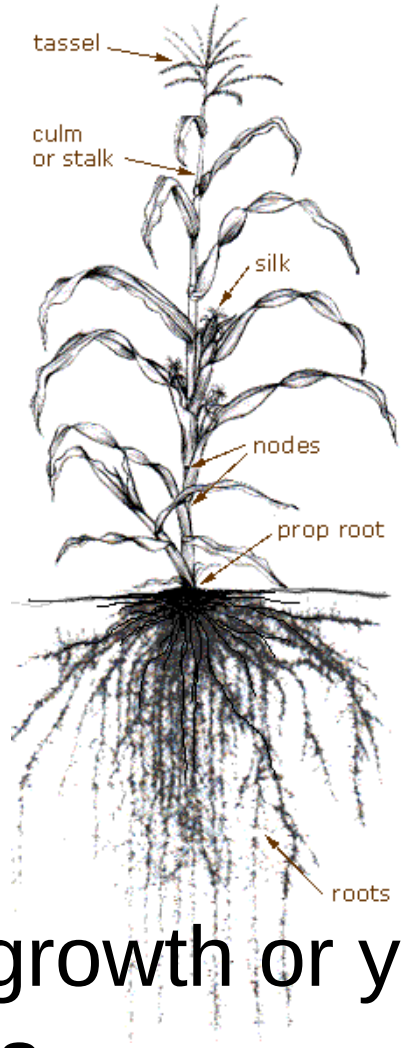
30 JUNE 2006 VOL 312 SCIENCE www.sciencemag.org

$[CO_2]$
today



=

$[CO_2]$
2050



No change in development, growth or yield under well watered conditions

Leakey (2009) *Proceedings of the Royal Society*

C_4 species dominate some of the most food insecure regions, but no data from such places.

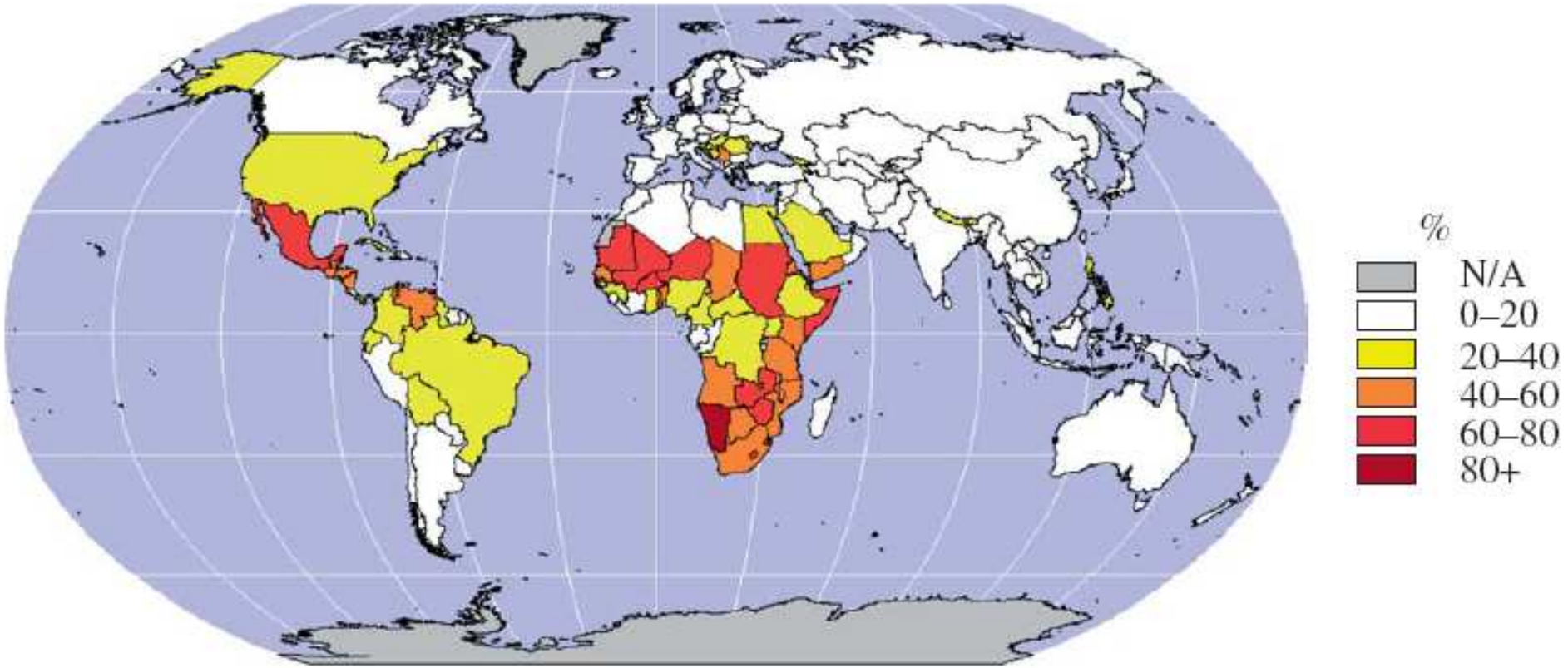
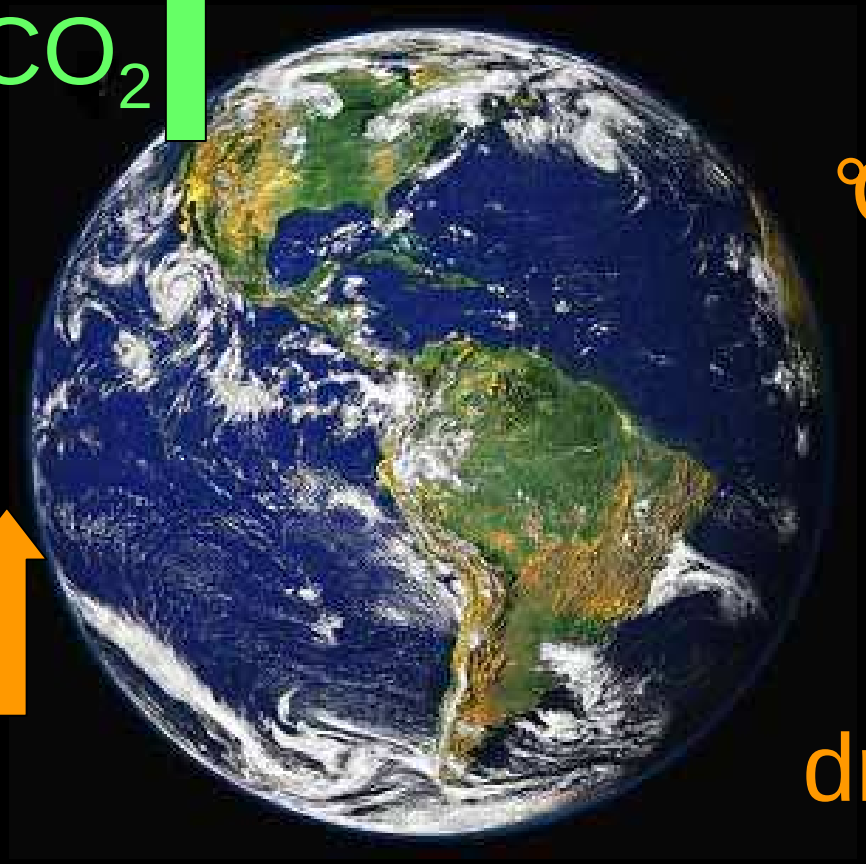


Figure 1. Percentage of agricultural land used for the production of C_4 crops in 2006. Estimates of national C_4 crop production area were taken from the ProdSTAT database, FAO (http://faostat.fao.org) (grey, n.a.; white, 0–20%; yellow, 20–40%; orange, 40–60%; red, 60–80%; dark red, +80%).


1) How will rising CO_2 contribute to climate change impacts on crop production in the 21st century?
2) How can we improve the situation?

Climate change is multifaceted



Two options for crop improvement:

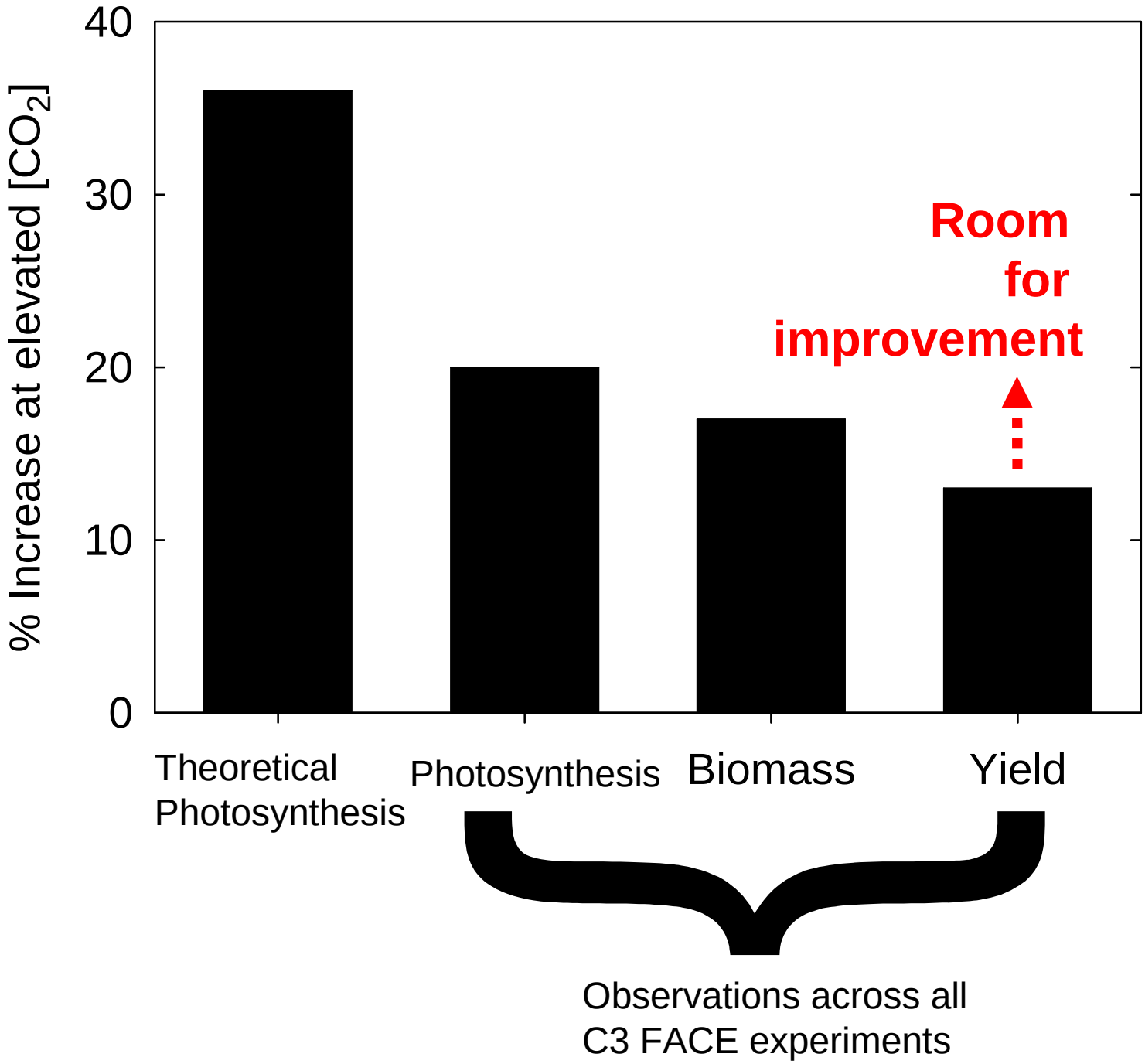
- *Reduce the negative*
- *Enhance the positive*

Temperatures, drought & flooding have always challenged agriculture.

Decades of research and plant breeding have dealt with these stresses.

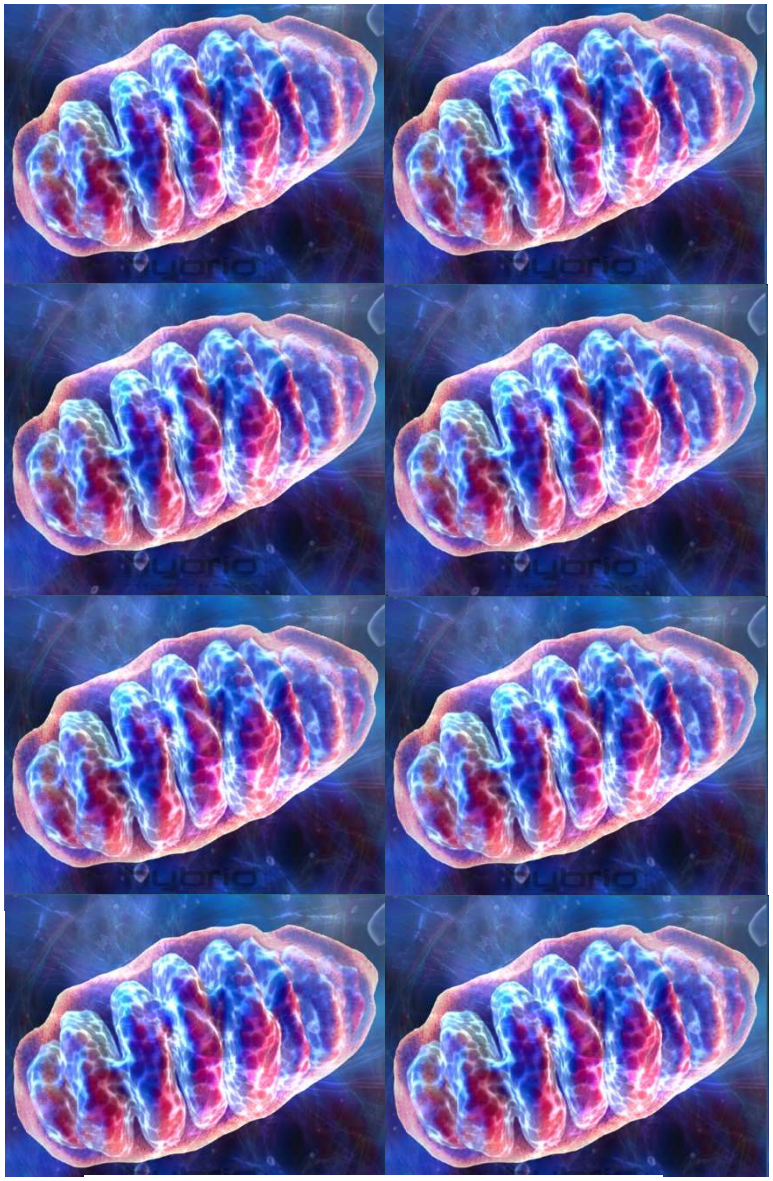
Biotechnological approaches are now making further progress.

But we have made no attempt to take greater advantage of rising CO_2


40
30
20
10
0
% Increase at elevated [CO2]
Room
for
improvement
Theoretical
Photosynthesis
Photosynthesis
Biomass
Yield
Observations across all
C3 FACE experiments

Genomic basis for stimulated respiration by plants growing under elevated carbon dioxide

Andrew D. B. Leakey[a,1], Fangxiu Xu[a], Kelly M. Gillespie[a], Justin M. McGrath[a], Elizabeth A. Ainsworth[a,b], and Donald R. Ort[a,b]

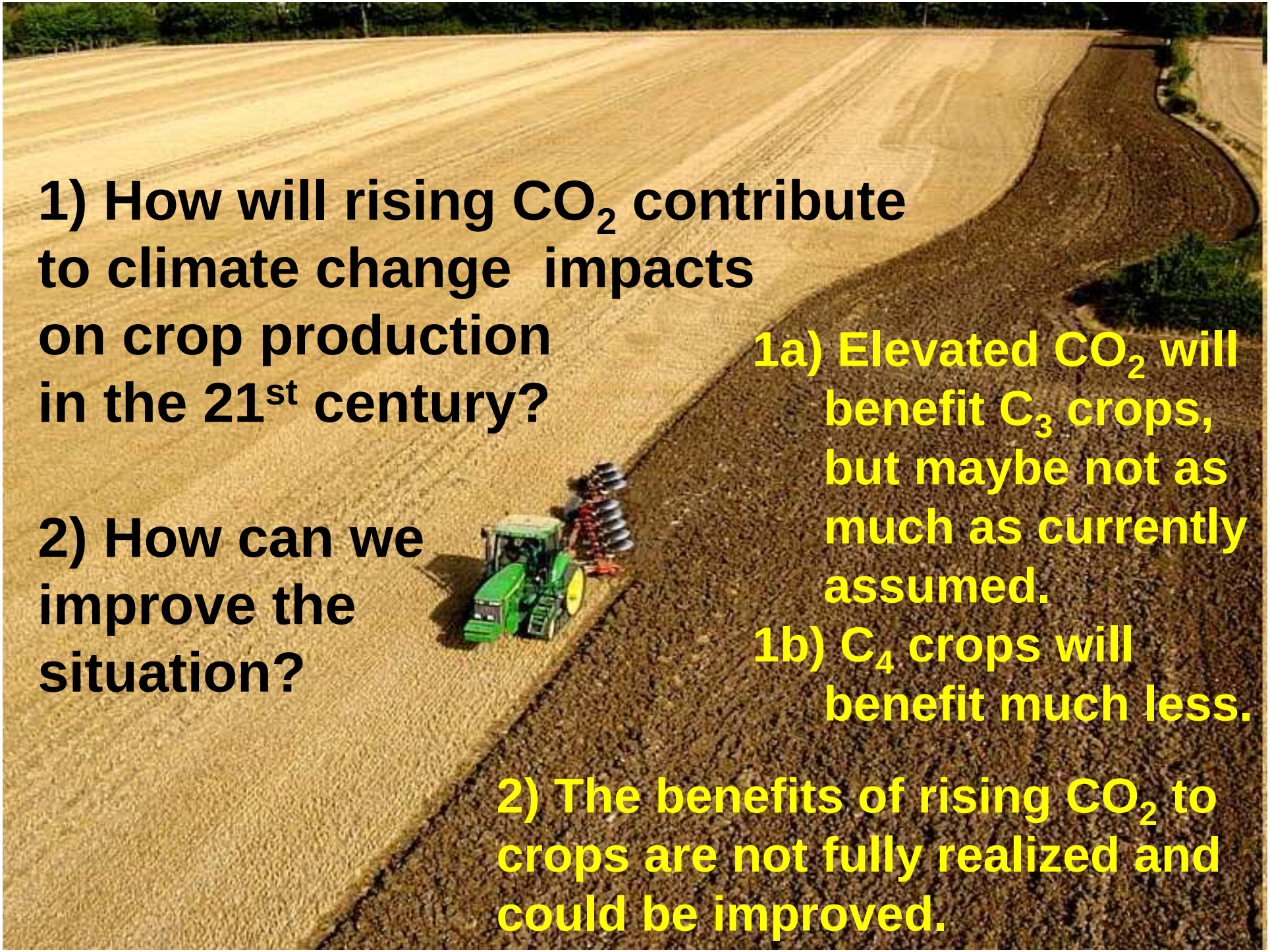


PNAS | March 3, 2009 | vol. 106 | no. 9 | 3597–3602

More mitochondria allow the cells in leaves to produce more energy to transport sugars to where they are needed for growth or yield.

We have identified over 600 genes whose expression is altered by growth at elevated CO_2.

We are testing which genes might be manipulated to improve the yield of crops at future CO_2 concentrations.


1) How will rising CO_2 contribute to climate change impacts on crop production in the 21st century?
2) How can we improve the situation?
1a) Elevated CO_2 will benefit C_3 crops, but maybe not as much as currently assumed.
1b) C_4 crops will benefit much less.
2) The benefits of rising CO_2 to crops are not fully realized and could be improved.

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Researchers

Faculty: Donald R. Ort (Theme Leader, Plant Biology USDA/ARS), May R. Berenbaum (Entomology), Hans J. Bohnert (Plant Biology), Evan H. DeLucia (Plant Biology), Andrew Leakey (Plant Biology), Stephen P. Long (Plant Biology)

Affiliates: Elizabeth A. Ainsworth (Plant Biology USDA/ARS),